Reverse Ion Acceleration by Laser-Matter Interaction

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ICOPS 2005 18 - 23 June 2005, Monterey, California
32nd IEEE International Conference on Plasma Science

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 2005**	2. REPORT TYPE	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Reverse Ion Acceleration by Laser-Matter Interaction**		5a. CONTRACT NUMBER **FA8650-04-C-2511**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **P Messmer; P Stoltz; C Nieter; Jean-Luc Cambier**		5d. PROJECT NUMBER **OSDB**
		5e. TASK NUMBER **R4QP**
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory (AFMC),AFRL/PRSA,10 E. Saturn Blvd.,Edwards AFB,CA,93524-7680**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT **N/A**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**17**	

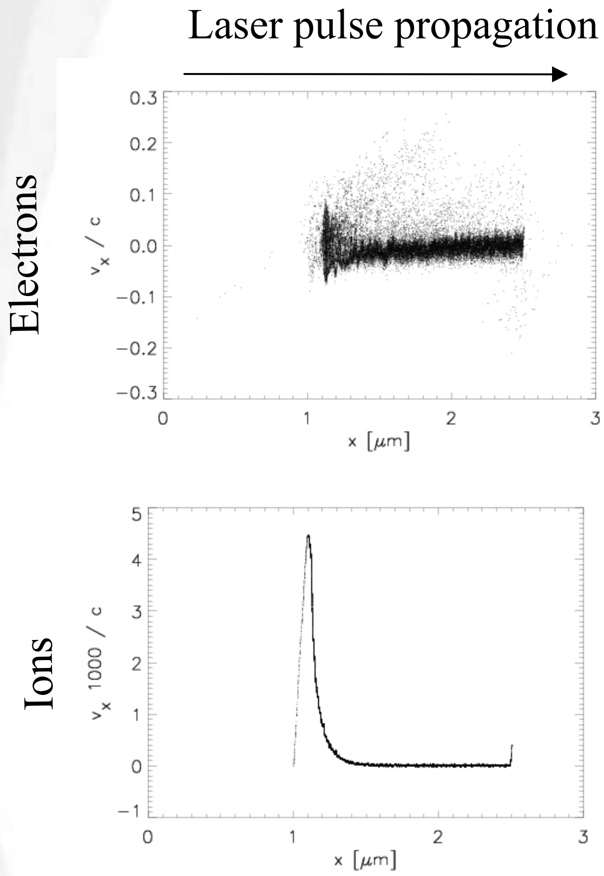
Outline

- Forward Ion Acceleration
- Ion acceleration in reflecting geometry
- Simulations with pre-ionized plasma
- Simulations including ionization
- Conclusions
- References

Introduction

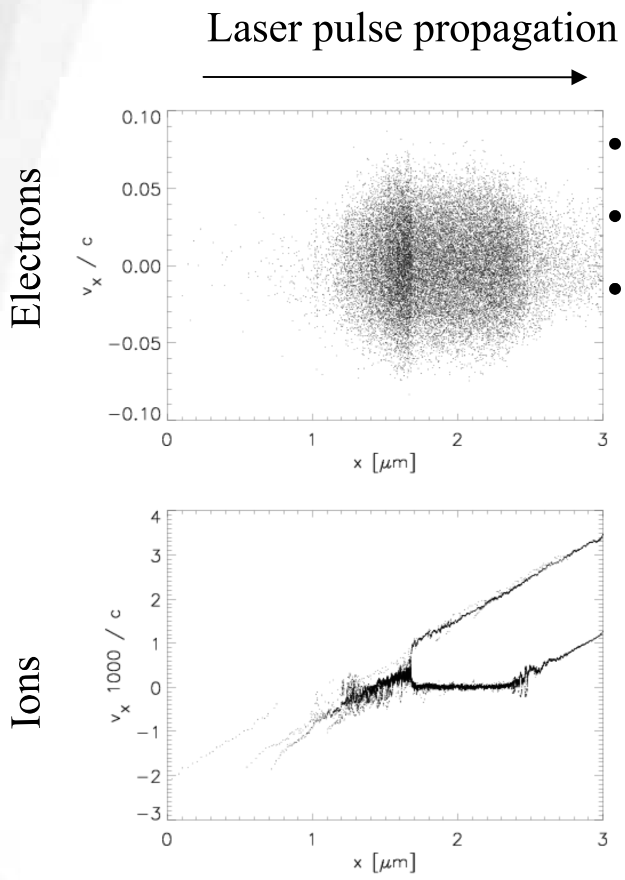
- Ion acceleration via laser-matter interaction is an attractive mechanism for several potential applications, e.g.:
  - compact size accelerators
  - diagnostic sources
- Common setup:
  - ultra-intense, ultra-short laser pulse hits over- or underdense foil target
  - Electrons ponderomotively accelerated and heated
  - Ions accelerated forward (same direction as initial laser pulse)
- Several mechanisms can be responsible for ion acceleration:
  - Sheath normal acceleration
  - Shock acceleration
  - Coulomb explosion
  - Adiabatic expansion
- For some applications, acceleration in backward direction is preferable!
- Investigation of different setups for reverse acceleration

Example of Laser-Matter Interaction



- Interaction of 100 fs laser-pulse with over-dense foil target propagating left to right
- During laser pulse (100 fs):
  - Electrons accelerated into foil via ExB
  - Overshooting at foil backside
  - Electron recirculation
- $\Rightarrow$ Electrostatic fields at front and back of foil
- $\Rightarrow$ Ions get accelerated in forward direction

Laser-Matter Interaction (Cont.)

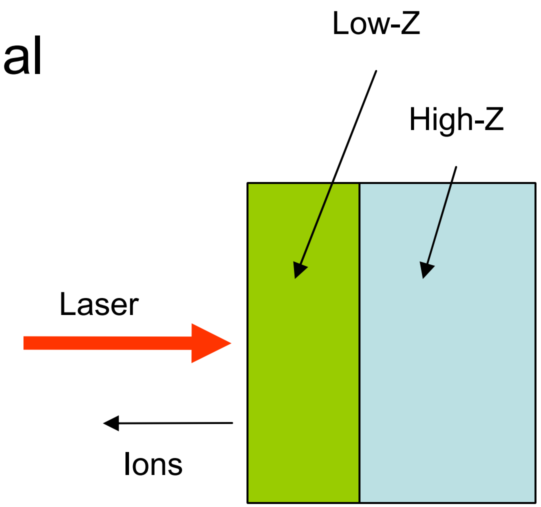


- After laser pulse (≈ 2ps):
- Electrons thermalize
- Ions continue to be accelerated
  - Sheath normal acceleration at back and front
  - Shock acceleration (if shock forms)

QUESTION:
Is there a way to accelerate ions only in one direction?

Two-Component Material

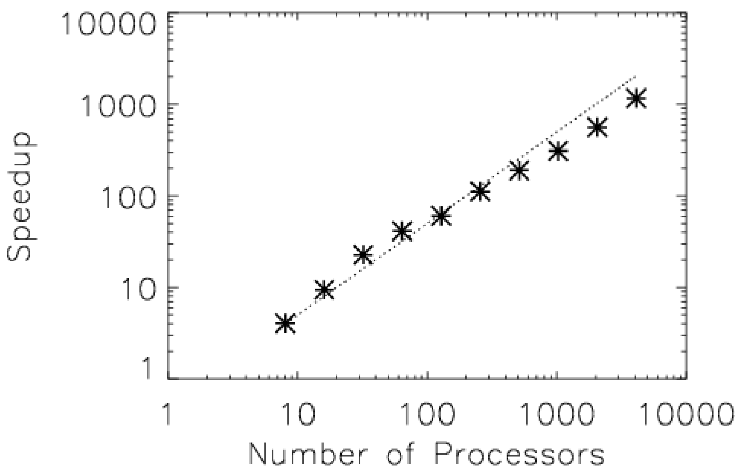
- **Overdense, high-Z target**
  - Laser pulse gets reflected
  - High-Z: electrons see strong potential
- **Underdense, low-Z coating**
  - Laser propagates through film
    - Ionizes the film
    - Accelerates some electrons
  - Second pass through film
    - More ionization
    - Accelerates more electrons and esp. ions, but now in backward direction



VORPAL

- Plasma simulation code/framework
  - PIC, Fluid, hybrid model
- Original design: Wakefield acceleration
- Nieter & Cary, J.Comp. Phys., **196**(2), 448, 2004

- Multi-Dimensional (N=1,2,3)
- Fully parallel
  - Scaling for > 4000 PEs
  - Flexible domain decomp
  - Dynamic load balancing
  - C++
- Output format: HDF5
- Postprocessing/Viz:
  - IDL, OpenDX, GnuPlot



http://www-beams.colorado.edu/vorpal/

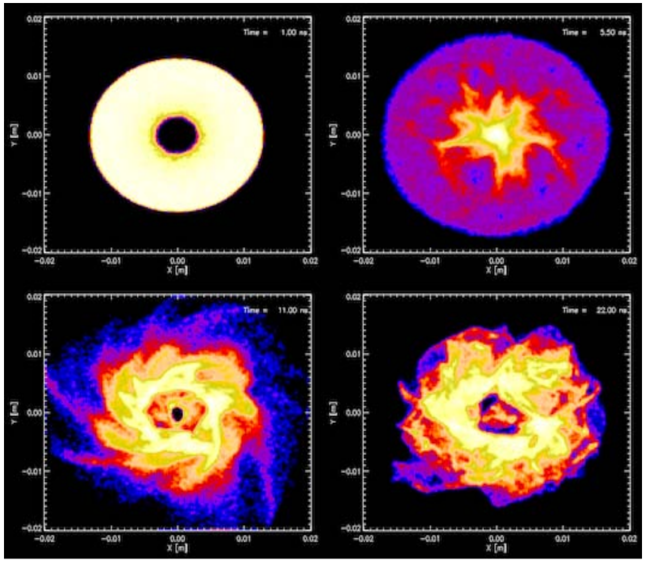
VORPAL Features

- **Full EM PIC model**
  - Moving window
- **Variety of particle sources, emitters**
  - Space Charge limited
  - Fowler-Nordheim
- **Parallel ES solver**
  - Based on Aztec (Sandia)
  - Variety of solvers, preconditioners
- **DSMC**
  - Being implemented
- **Ionization**
  - Field ionization
  - Impact ionization under development
- **Direct Coulomb interaction**
  - Hermite integrator

Some Applications of VORPAL

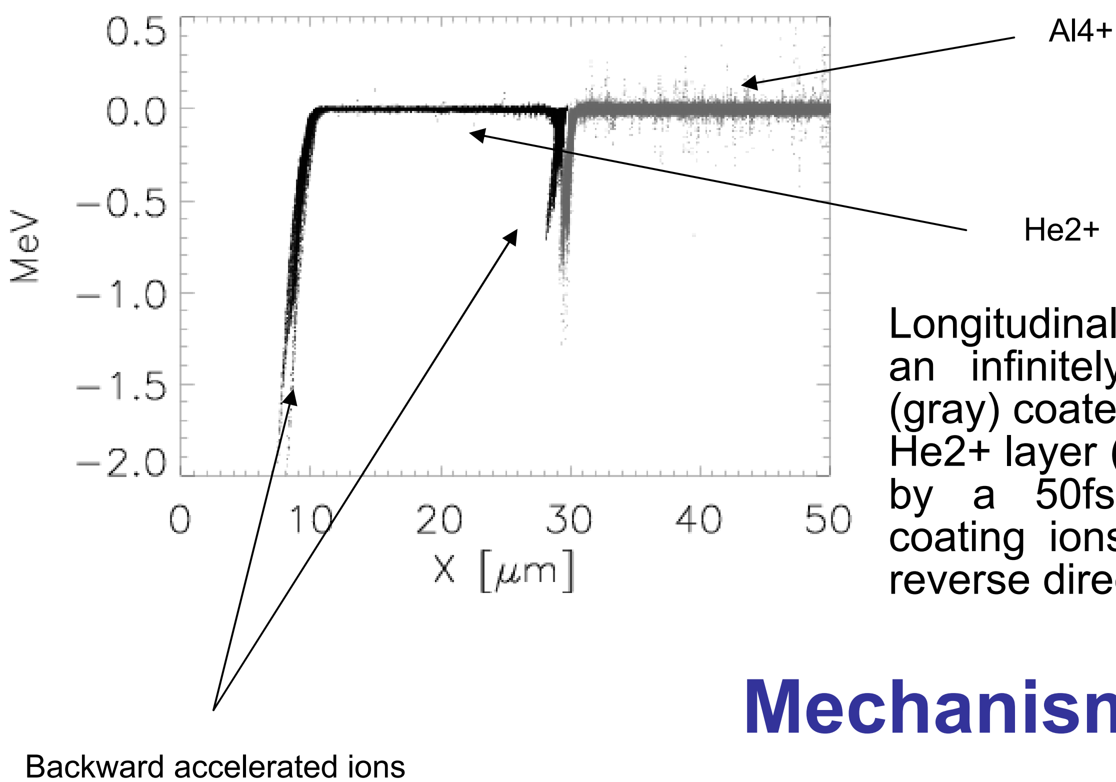
- Wakefield acceleration
- Electron cooling for RHIC
- High-power microwave breakdown
- Photonic bandgap structures

- Debris propagation in IFE chambers
- Dusty plasmas
- Gamma-ray bursts
- Magnetic reconnection
- Laser-Overdense interaction



Time evolution of the ion density in a 2D VORPAL simulation, including debris ions, debris electrons, background ions and background electrons.

Pseudo 2D simulations



Longitudinal ion phase space of an infinitely thick Al4+ target (gray) coated with a 30 mm thick He2+ layer (black) after being hit by a 50fs laser pulse. The coating ions are accelerated in reverse direction.

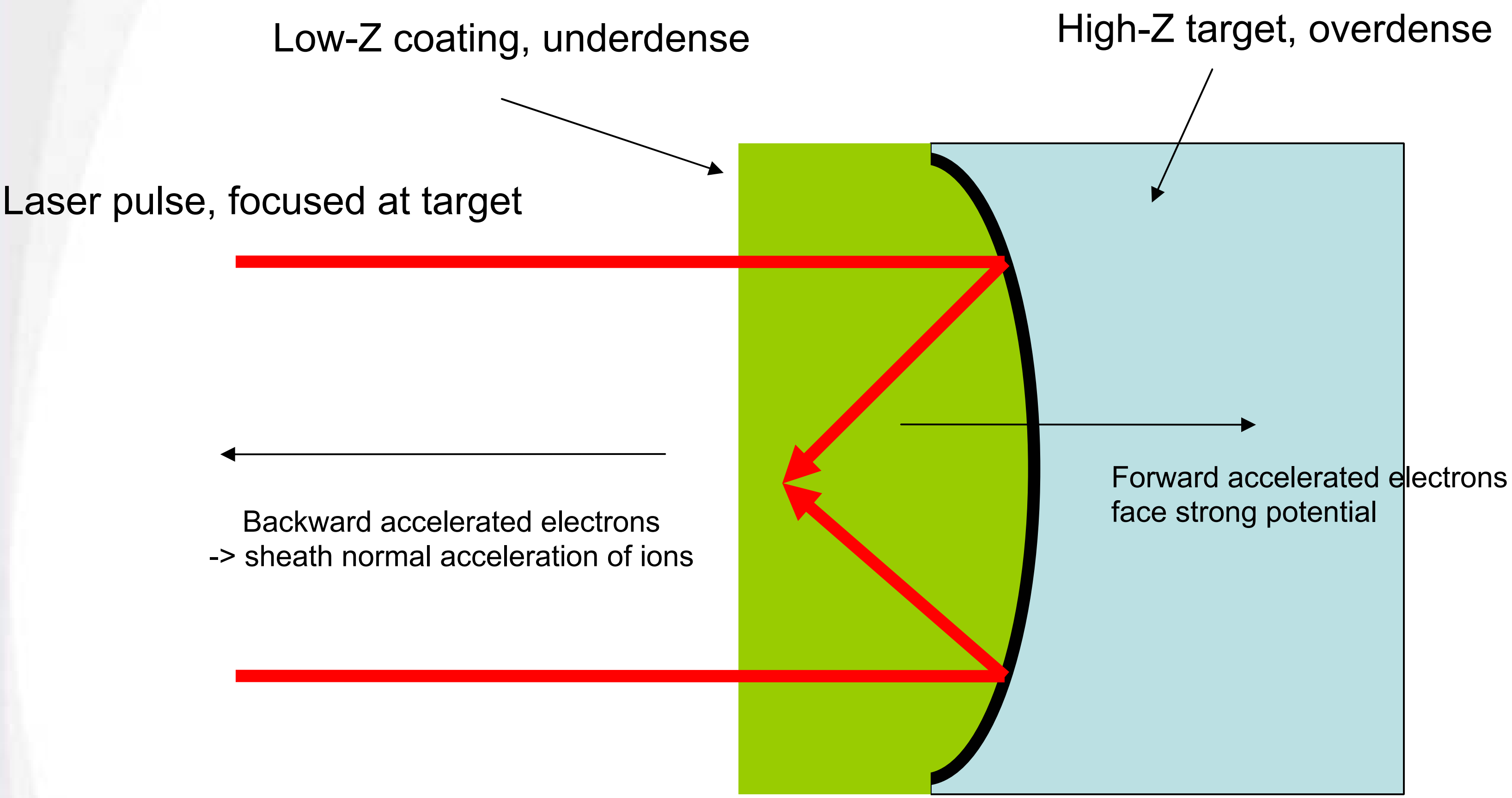
Mechanism works!

What about ionization? Peak intensity? ….

Ionization within coating

- Acceleration in backward direction if ionization happens only after reflection off the target
- Shape target as focusing mirror

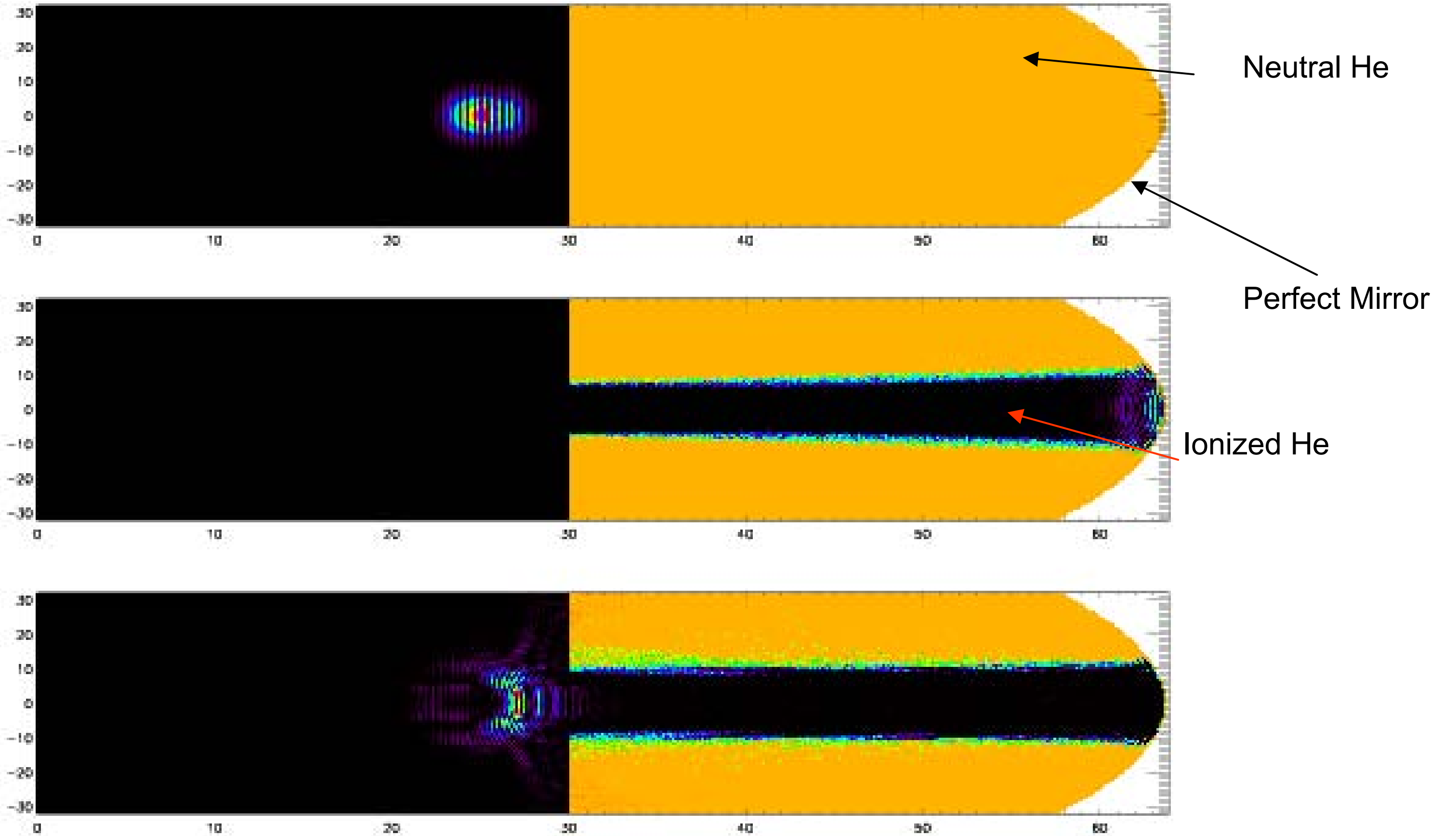
Setup



Low-Z coating, underdense
High-Z target, overdense
Laser pulse, focused at target
Backward accelerated electrons
-> sheath normal acceleration of ions
Forward accelerated electrons
face strong potential

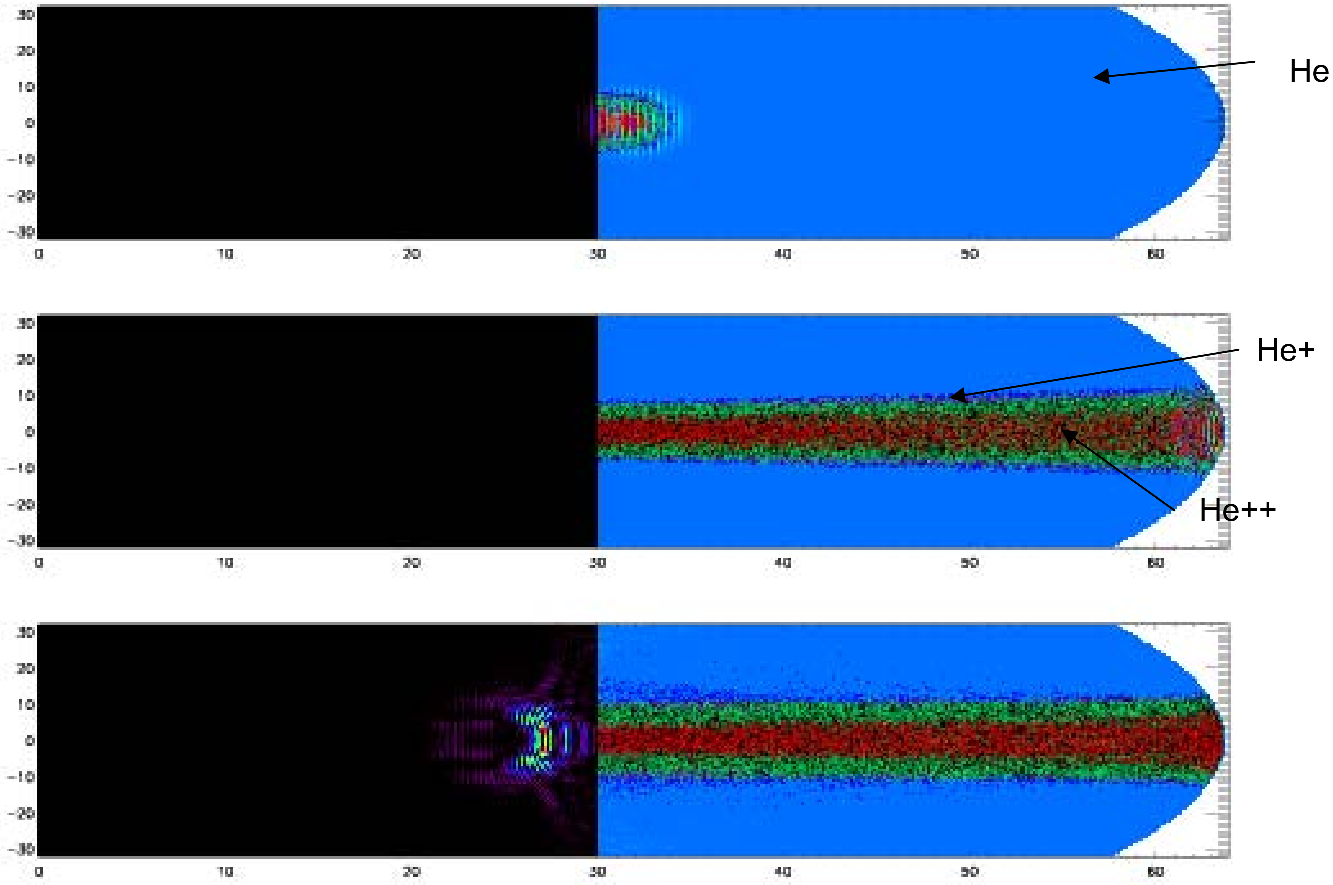
Coated mirror (incl. ionization)

Neutral He contours



Coated mirror (incl. ionization)

He Ions contours

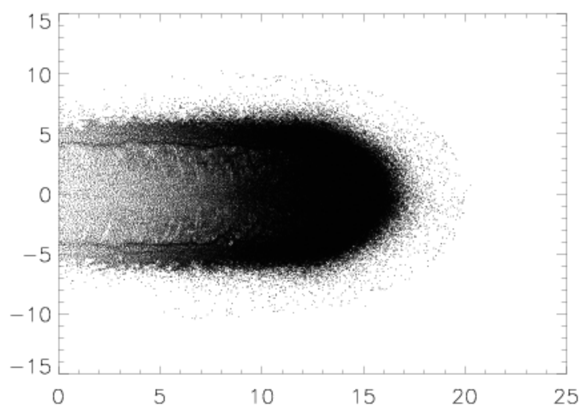


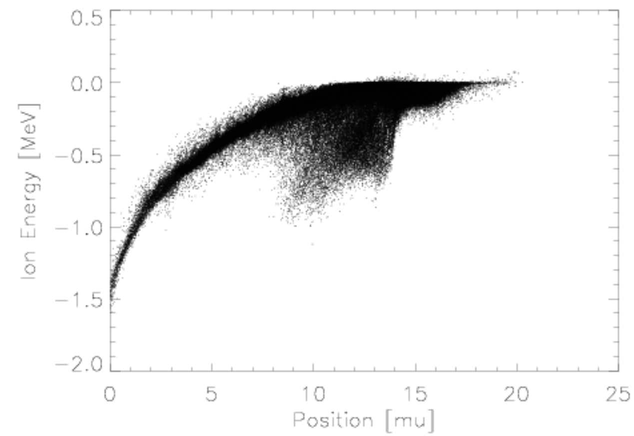
Backward Ion acceleration ?

YES!

He++ Position

He++ Energy





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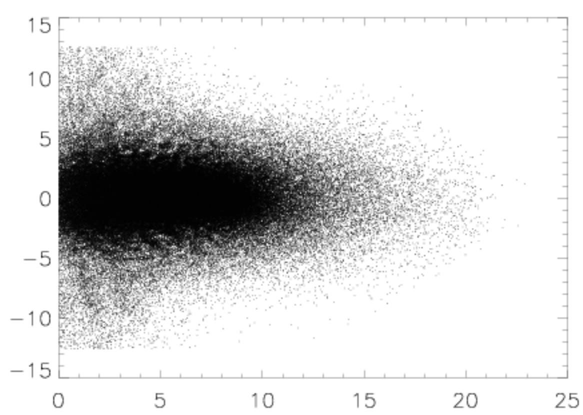

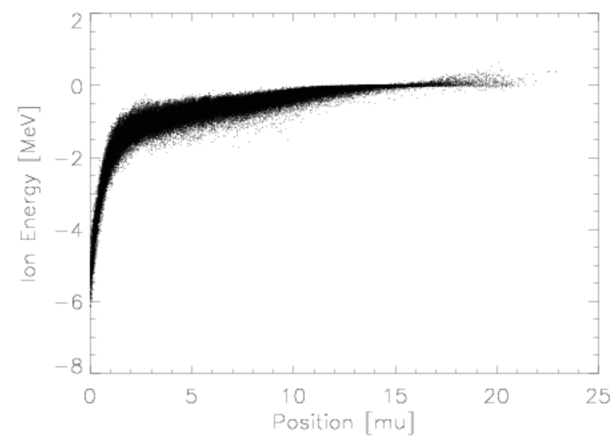

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Summary

- Presented simulations of laser-matter interaction
  - Different model for matter: pre-ionized, including ionization
  - Different geometries: plane parallel coating, focusing mirror
- Ion acceleration in reverse direction has been observed
- Future work:
  - More parameter studies to optimize process: coating thickness, Z-ratio, laser focus, mirror geometry
  - Dynamic focusing (pre-pulse creating “mirror”)

This work was supported by OSD SBIR Phase II Contract XXXXX and Tech-X Corporation

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